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(54) FOREIGN PARTICLE DETECTOR

(71) We, BORDEN INC. a corporation organised under the laws of the State of New Jersey, United States of America, 50 West Broad Street, Columbus, Ohio 43215, United States of America, do hereby declare the invention for which we pray that a patent may be granted to us and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to an apparatus for inspecting objects, for example containers which contain processed foods.

Detection of foreign particles in processed foods has been a critical problem in quality control programmes, as the presence of such particles may cause injury to the consumer. As a result inspection devices have been developed which can detect and reject a jar of food product containing a foreign particle.

The basic problem with such devices is one of detecting millimetre and larger size foreign fragments within filled containers at realistic throughput rates. Detection of foreign fragments with X-ray equipment uses localized attenuation caused by the fragment which, with presently available equipment, requires a difference of attenuation of at least about 10% to be detectable using an X-ray radiation imaging system.

According to the present invention there is provided an inspection apparatus comprising an X-ray source connected to an AC power source for delivering X-rays across a path; means connected to the AC power source for continuously moving test objects along the said path, the test objects being so moved along the path that they arrive at the inspection station at a predetermined point in the AC cycle; means actuated by the said test objects for actuating said AC power source to allow X-rays to be emitted as one of the test objects becomes registered in an inspection station; detecting means for receiving the X-rays; means for analyzing the X-rays received by the said detecting means and comparing them with a pre-set value; and means for rejecting certain of the test objects in response to actuation by said analyzing and comparing means.

The apparatus can inspect filled containers for the presence of foreign fragments such as glass, metal or stone. The inspection process has no harmful effect on the food in the containers, the container itself or the operating personnel. Product flavour and appearance are also unaffected by test conditions and the exposure levels are too low to achieve any sterilizing effect. The maximum external radiation at peak tube voltage and peak testing rate occurs close to the tube shield at the edge of the opening for the test beam. This location is impossible to reach with more than a small portion of the human body. A physical guard on the conveyor lines can be installed to prevent the very low level of radiation from reaching any part of the operator's or observer's body. Inside the conveyor line guard, the stray radiation level is so low as to fall under the category of "Exempt Protective Installation" promulgated by U.S. Department of Commerce, Handbook #93, p. 1, item 2-1.

Sensitivity of the inspection device depends on many variables including glass container characteristics and normal variations in product density. Container characteristics include consistency of wall thickness, angle between the wall and the base, consistency of base thickness, presence of ribs or ridges or areas of increased or decreased thickness for decoration or for other purposes and contamination of glass itself.

The probability of detection is also influenced by particle position in the jar relative to the X-ray field of view. A particle at the edge of the field of view must be larger than a particle at the centre of the field of view to be detected. The field of view subjected to inspection by the X-ray imaging process is preferably limited by an outline mask which

excludes from inspection the wall of the jar base and the closure. The configuration of the outline mask is matched to a particular jar.

The invention is described below in connection with the accompanying drawings in which:

Figure 1 is a diagrammatic perspective view of an embodiment of the inspection device for inspecting sealed glass containers moving at conveyor speed when the inspection is performed in a period of a few one-hundredths of a second;

Figure 2 is an electrical block diagram showing the major logic functions of the system which senses, by a combination of electronic and optical means, the localized attenuation caused by a foreign particle within a container and subsequently rejects that container.

The preferred embodiment of the invention disclosed in Figures 1 and 2 is adapted to inspect a filled glass container electronically and optically for the presence of foreign particles. Glass jars 12 are shown disposed on and moved by conveyor 14 which includes link chain 16. The jars 12 should be spaced about one inch apart to facilitate triggering of a photo cell when a jar enters the inspection area and to facilitate ejection of the jars containing foreign matter at an appropriate point. As the inspection area is approached, the jars are impelled by a spring biassed guide rail 18 against a timing screw 20 and cradled in the screw flights. The timing screw can be obtained from Earnst Manufacturing. The timing screw is driven by a motor 22 through a belt 24. A motor such as permanent magnet 3600 RPM synchronous motor manufactured by McLean under model No. #47GBH1B9, which has a 15:1 gear reducer, may be used. The motor is connected into a power line which also supplies power to the electronic portion of the inspection system. By virtue of being driven by the synchronous motor which is provided with a 15:1 gear reducer, the bottles are mechanically in phase with the power line. Since the jars are in phase with the power line, the inspection area is located as close as possible to the terminal point of the timing screw so that when a jar enters the inspection area, an in-phase pulse of X-rays shall be emitted to initiate an inspection cycle.

Although it is not essential the speed of the belt should preferably be adjusted to the linear movement imparted by the timing screw in order to avoid motion non-uniformities and the problems associated therewith. In the preferred embodiment, the belt speed is 90 feet per minute and due to a 15:1 gear reduction, the inspection rate is 240 jars per minute. At this rate, each slot in the timing screw is filled. Although at lower rates one or more of the slots will be empty, the inspection cycle will take place in exactly the same time and rate independent of the input rate. It should be apparent that the rate can be increased well beyond 240 jars per minute.

The use of the timing screw with the synchronous motor is a simple and practical solution to a problem of registering a moving test object with a timed burst of X-rays without having to intermittently arrest the motion of the conveyor or the test object.

It is the timing screw, which is in phase with the power line, that delivers the jar to the inspection area at the instant that a pulse of X-rays is released. As the jar leaves the timing screw, it enters the inspection area in which it is interposed between an X-ray source 26 and an image intensifier 28. The X-ray source used is preferably a self-rectified X-ray head. In the preferred embodiment the source is Americana X-ray head model WX900 and the image intensifier is the Machlett dynascope 9TZ including DF2 power supply. In this position, the jar interrupts a light beam from a trigger lamp 30 to a trigger photocell 32 which causes an electrical pulse to be generated from the power line and the inspection cycle to begin. Since the jar is mechanically in phase with the power line which also produces the trigger pulse, the jar will be in registry for a shot of X-rays when the initial negative cycle of AC line causes the X-ray pulse to be generated. The duration of the X-ray pulse is one-half of a complete line cycle of 1/120th of a second. The succeeding positive half cycle of the line initiates image scanout by the closed circuit TV system 34 which continues for a complete line cycle or 1/60th of a second. The TV camera is preferably the Visual Educon Dage 800 camera with separate mesh vidicon and Concord TVL 14 close-up lense. As should be apparent, the complete inspection cycle is 1/40 of a second (1/120+1/60).

Positioned between the X-ray source 26 and jar 12 is an X-ray mask 31 which functions to flatten out gross non-uniformities of the X-ray beam itself. The mask can be made with an aluminium backing 1/16" in thickness with a layer of solder or lead or a mixture thereof thereon facing the X-ray source. This layer is generally convex and about 1/8" thick. The shape of the X-ray mask is dictated by the fact that the X-ray beam is strongest at the centre and weakens towards the edges. This mask produces a field which is within 30% of being uniform.

If a foreign particle is present in a jar, the X-rays passing through the jar will impinge upon the front surface of the image intensifier and will form an image which is attenuated in the region of the foreign particle. Since the diameter of the entrance pupil in the image intensifier is up to 9 inches, this permits articles of up to 8 inches in height to be inspected in one pass. A larger article can be inspected by passing them through the X-ray field a number of times until all of it has been inspected. The X-ray shadow in the image

intensifier is amplified electrically about 5000 times and appears as a visible minified image on the intensifier output screen 29, which is approximately one inch in diameter.

An outline mask 36 is positioned between the jar and the front face of the image intensifier 28. The outline mask can be made of lead or any other material which can effectively absorb and thus block X-rays. The mask has the outline of a jar which corresponds to the jars being inspected. The outline mask is necessary to block X-rays outside of the bottle outline from entering the image intensifier. In absence of the outline mask, the powerful unattenuated X-rays would diffuse into the bottle outline and blanket out any foreign particles disposed at the edge of the jar.

Another mask 38 is positioned between the output screen 29 of the image intensifier 28 and the TV camera 34. This mask 38 is simply a film negative of a control jar taken from the output side of the image intensifier. This mask compensates for difference in density of the various products and bottle configuration such as shape of bottle, and ribs or ridges on the bottle. A different mask is made and used for each different product. The non-uniformities due to the X-rays in the image on the output side of the product mask are further reduced by the mask 38 to about 3%.

After passing through the mask 38, the light is detected by the closed circuit camera 34 and converted to video signals which are inverted, gated and applied to a TV monitor 40. The TV monitor 40 is preferably the Sony View Finder Monitor model AVF 3200. Since the image is electronically inverted, it appears on the monitor as dark except where additional attenuation is obtained from a foreign particle. Therefore, when a bottle is being inspected, a bright spot is seen when a foreign particle is present in addition to a partial outline of the bottle.

The light from the monitor 40 is passed through an edge mask 42. This mask functions to block out extraneous light outside the jar outline and can be made of any suitable material which is not transparent. After passing through the edge mask 42, the light is converted into electrical signals by a photomultiplier 44, amplified and detected by a level detector. The photomultiplier tube is preferably the RCA 931 A tube. When the light output exceeds a pre-set level, a reject pulse occurs, a count is stored in the reject counter and in a shift register. The shift register meters off a fixed distance on the conveyor by sensing links in the link chain 16 by means of a counting photo cell 46 and operates a reject solenoid 48 at a fixed distance from the inspection area. When the bottle reaches a reject station 50, it is ejected by the reject solenoid 48. In the preferred embodiment, ejection takes place 38 links past the inspection area. Since each link is 5/8", this distance is about 2 feet. If only one reject pulse is registered, only one actuation of the reject solenoid will occur. If a series of reject pulses are inserted, a series of reject pulses will occur, all delayed by a respective pre-set distance.

The major logic functions of the system are illustrated by the block diagram in Figure 2.

When the leading edge of a jar interrupts the light from the trigger lamp 30, a pulse is generated by the trigger photocell 32 which is sent to a timing logic 52 which initiates the inspection cycle. Since the energy for the X-ray pulse is directly derived from the power line, the inspection cycle is also phased to the power line. The power line, therefore, is also used in the timing logic. When the line starts to go negative subsequent to the trigger, it is sensed by the timing logic and a high power pulse is generated for the X-ray source. Although this pulse has a duration of one-half cycle of the line, that is 1/120th of a second, because of the nonlinear relationship between voltage and usable X-ray energy, only a portion of this 1/120th of a second is actually used for the detection process. Therefore, the effective exposure time is only a few milliseconds. From the timing logic 52, a pulse is sensed by a zone and multi-vibrators unit 64 where, in conjunction with a gate in the processing amplifier and a gate unit 54, the monitor is blanked only for the portion covering the edge of the jar. This is done by triggering a multivibrator in the unit 64 which closes a gate in the unit 54 for a split second that it takes to blank the edge of the jar. The multivibrators are set separately in each zone and are adjusted to completely blank out the monitor in the leading edge region of the jar. After an initial half cycle of the line when a burst of X-ray energy is released, scanout takes place during the succeeding full line cycle.

As previously described, the shadow image of the jar produced by the X-ray source is converted to a visible minified image by the image intensifier 28, changed to a scan video signal by the TV camera 34, and passed through the processing amplifier and gates unit 54 to the TV monitor 40. A signal from the camera 34 through a sync processor 74 triggers multivibrators in the unit 64 to generate zones which are scanned in the manner described. The unit 54 is part of the camera 34. The output light from the monitor is detected by the photomultiplier 44, applied to a gated integrator 56, a level detector 58 and a reject one shot 60, which generates a pulse when a reject is present. This pulse is entered into the shift register 62 and after a pre-set number of pulses are counted, which corresponds to a given conveyor distance, the reject solenoid 48 is actuated and the jar containing a foreign particle is ejected.

The system is completely insensitive to signals except during the unblanking and zone periods. The unblanking and sensitivity section is formed by quite a straightforward process. First, there is a general rectangular zone which is sufficiently large to encompass the entire jar. The zone is defined by the zone and blanking multivibrators in unit 64 in conjunction with processing amplifier and gates in the unit 54. This zone defines the inspection area within the outline of a jar. In the vertical direction, four additional zones are used. These may be set from top to bottom for any regions of the jar desired.

Since a jar is normally not completely cylindrical or uniform in wall thickness throughout vertical dimensions, the sensitivities may be increased in the areas of uniformity and somewhat decreased in the areas where the masking cannot remove all the non-uniformities. As the camera continues to scan the image in the horizontal direction, a sync pulse is applied to zone and blanking multivibrators in the unit 64 which triggers a blanking multivibrator in the same unit. In each of the four zones, in addition to multivibrators which blank out the leading edge of the jar, a second multivibrator determines the length of the inspection period. If the jar is completely cylindrical, all of these second set of multivibrators are set the same. In regions where the jar has different cross sections, the multivibrators, that is the inspection time, is correspondingly altered.

The integrator 56, which is used to accumulate the electrical signals generated from the light output from the monitor 40, is likewise dead whenever the monitor signals are blanked. This provides double insurance against any noise spikes entering the system and causing false rejects.

With a large completely cylindrical jar, approximately 200 horizontal scan lines would be observed from the top to bottom of the jar. Each of the four zones, therefore, would contain about 50 lines. At the end of each of these zones, the integrator which accumulates light is reset. Therefore, if no provision were made to deal with this problem the light from the particle would need to be larger than the accumulated light from 50 normal scanlines. In addition, however, within each four zones are ten-line multivibrators 66, which dump or reset the integrator at the end of each ten horizontal lines. After every scan of the ten lines, integrator 56 is cleared by means of a gate unit 68. Therefore the light output from the particle need be only larger than the light output from 10 horizontal lines containing no foreign matter.

The monitor is quite dark except for some random noise and the particle produces a bright image within the outline mask. This light, then, generates the reject signal. The left outline or the leading edge of the bottle is completely blanked electrically. In those regions of the bottle where the diameter changes cross sections through-out a single zone, the light from the right hand side of the bottle is blanked by the outline mask. The larger the particle or the more dense it is, the larger will be the output signal. Zone sensitivities 70 are individually set in a zone selector 72 for the particle size desired within a given zone. Selection of the particular sensitivity or threshold level of light in any desired zone is a preferred feature of the inspection device described herein.

The circuitry used in the inspection device described above is conventional as evidenced by U.S. Patents 3,580,997 and 3,390,769. In fact, the bulk of the circuitry can be purchased in a single unit from Electro Data Concepts under designation 3047. This unit includes the timing logic 52, processing amplifier and gate unit 54, sync processor 74, zone and blanking multivibrators unit 64, ten-line multivibrators 66, gate unit 68, integrator 56, level detector 58, reject one shot 60, shift register 62, zone selector 72 and zone sensitivities 70.

The invention is not restricted in its application to any particular article. The substance inspected can be in glass, metal or plastics containers or can be packaged in plastics or paper bags. The term "containers" is used herein to mean anything which can be used to store or package articles whether it be paper or plastic bags or jars, bottles or cans made of substantially rigid material such as metal glass and plastic. In some applications, the use of the monitor, which converts electrical signals from the camera into visual images, can be dispensed with and the signals from the camera processed in a known manner. Under some operating conditions, the inspection device can be successfully operated without the edge mask which can be made of any material which does not transmit light, such as cardboard. Although spacing of about one inch between test objects is recommended, this spacing can be reduced and even entirely eliminated so that the test objects are in contact during the inspection process. The circuits in the inspection device are solid state, integrated circuits which are preferably isolated from the high power AC source, but isolation may not be required at some sites. Generally speaking, the minimum detectable size for glass containers is roughly one-half the wall thickness of the containers but this can be still further reduced, and under certain operating conditions it may be possible to detect foreign particles of a size approaching the distance between the scan lines. Since the inspection device is so adjusted that registry of a test object at the inspection station is within 1/16th of an inch, if registration is off by more than that value, the test object will be rejected as if it contained a foreign frag-

ment. The 1/16th of an inch tolerance can be adjusted to any desired level. Although a constant potential X-ray head can be used, a self-rectified X-ray head which uses AC power is preferred because it costs a great deal less and is particularly adapted to the type of inspection performed herein. It is known that the X-ray beam is most intense at its central point and for this reason, an X-ray mask is preferably interposed to flatten out the X-ray beam. With this in mind, the exterior outline of the mask is therefore convex although a filler can be used to make the exterior surface of the mask dimensionally flat and still perform the same function.

The distance between the end of the timing screw and the inspection station is so adjusted that when a test object enters the inspection station, it will coincide with the triggering of the X-ray source. For this reason, the distance between the timing screw and the inspection zone should be kept to a minimum. The inspection station coincides with the position of a test object in which it is in registry with the test object outline in the outline mask.

WHAT WE CLAIM IS:—

1. An inspection apparatus comprising an X-ray source connected to an AC power source for delivering X-rays across a path; means connected to the AC power source for continuously moving test objects along the said path, the test objects being so moved along the path that they arrive at the inspection station at a predetermined point in the AC cycle; means actuated by the said test objects for actuating said AC power source to allow X-rays to be emitted as one of the test objects becomes registered in an inspection station; detecting means for receiving the X-rays; means for analysing the X-rays received by the said detecting means and comparing them with a pre-set value; and means for rejecting certain of the test objects in response to actuation by said analysing and comparing means.

2. An apparatus according to claim 1 wherein the said means for continuously moving the test objects is a timing screw driven by a synchronous motor synchronized with the AC power source.

3. An apparatus according to claim 2 wherein the X-ray source is a self-rectified X-ray head and the synchronous motor is a permanent magnet synchronous motor.

4. An apparatus according to any preceding claim including an X-ray mask interposed between the X-ray source and the test objects as they move past the inspection station, the X-ray mask functioning to render the X-ray beams more uniform in intensity.

5. An apparatus according to claim 4 wherein the analysing and comparing means includes an image intensifier with an output screen for electrically amplifying the X-ray image of a test object and converting it to a visible minified image on the output screen and a TV camera for converting the image to video signals which are electronically inverted so that the image is dark except where additional X-ray attenuation occurs as a result of the presence of a foreign particle in a test object.

6. An apparatus according to Claim 5 wherein a product mask in the form of a negative image of a control test object is disposed on the output side of the image intensifier for compensating variations in the test objects.

7. An apparatus according to Claim 6, wherein the test objects are glass jars containing an edible substance and wherein the product mask is a film negative of a control test object taken on the output side of the image intensifier and is used to compensate for variations in density of the edible substance and various irregularities on or in the glass jars.

8. An apparatus according to Claim 7 wherein the analyzing and comparing means further includes a monitor which receives the image from the image intensifier after the image has passed through the product mask, and a level detector; the apparatus further including an edge mask on the output side of the monitor for blocking out extraneous light from the monitor, a photomultiplier detector which converts the image from the monitor into electrical signals, means for amplifying the electrical signals from the photomultiplier detector, and means for integrating the amplified electrical signals from the photomultiplier detector, the rejecting means operating to reject any glass jar for which the integrated value exceeds a certain pre-set value.

9. An apparatus according to Claim 8 wherein the analyzing and comparing means further includes means for defining a main inspection zone, means for sub-dividing the main zone into secondary zones for inspection in each of the secondary zones, means for separately integrating the signals for each of the secondary zones, means for comparing the integrated value of each secondary zone with a pre-set value, the rejecting means operating to reject a test object if the pre-set value is exceeded.

10. An apparatus according to Claim 9 including means for separately varying inspection sensitivity in each of the secondary zones.

11. An apparatus according to any preceding claim including a timing logic circuit for initiating inspection of a test object by triggering the X-ray source in phase as a test object comes into registry for inspection at the inspection station.

12. An apparatus for inspecting containers filled with a product, comprising an X-ray source for delivering at an inspection station X-rays across a path in the form of discrete

pulses; an X-ray mask disposed in front of the X-ray source for imparting uniformity to the X-ray pulse; conveyor means for continuously moving the containers through the inspection station so that the X-ray mask is interposed between the X-ray source and the containers as the containers move through the inspection station; an outline mask which blocks out X-rays passing beyond the outline of the containers as the containers move through the inspection station and allows passage of the X-rays falling within the outline of the containers; an image intensifier with an output screen which electrically amplifies the image formed by X-rays and converts it to a visible image on the output screen, the image intensifier being disposed on the output side of the outline mask; a product mask, in the form of a negative image of a control test object, disposed on the output side of the image intensifier for compensating container and product variations; a TV camera which receives the image through the product mask and converts the image to video signals which are electrically inverted; a monitor which receives said inverted signals from said TV camera and converts them into a visual image which is dark except where additional X-ray attenuation occurs as a result of the presence of a foreign particle in the container; and means for deriving light from said visual image and comparing the light with a pre-set value; and means for rejecting the container when the pre-set value is exceeded.

13. An apparatus according to claim 12 wherein the X-ray source is a self-rectified X-ray head which operates on AC power.

14. An apparatus according to claim 12 or 13 wherein the light deriving and comparing means comprises an edge mask on the output side of the monitor for blocking out extraneous light from said monitor, a photomultiplier detector for converting the image from said monitor into electrical signals, means for amplifying the electrical signals from said photomultiplier detector and means for integrating the amplified electrical signals from said photomultiplier detector, the rejecting means operating to reject a container for which the integrated value exceeds a certain pre-set value.

15. An apparatus according to claim 12, 13 or 14 wherein the X-ray mask consists of an aluminium backing and a layer of solder, lead or a mixture thereof, the said layer having a generally convex exterior outline.

16. An apparatus according to any one of claims 12 to 15, wherein the outline mask is made of lead and said product mask is a film negative of a control container taken on the output side of the image intensifier.

17. An apparatus according to any one of claims 13 to 16 including means for defining a main inspection zone, means for subdividing said zone into secondary zones for inspection in each of the secondary zones, means for separately integrating the signals for each of the secondary zones, means for comparing the integrated value of each secondary zone with a pre-set value, the rejecting means operating to reject a test object if the pre-set value is exceeded.

18. An apparatus according to claim 17 including means for varying inspection sensitivity in each of the secondary zones.

19. An apparatus according to any one of claims 13 to 18 wherein the conveyor means includes a timing screw driven by a synchronous motor synchronized with an AC power source, the said apparatus including a timing logic circuit connected to the AC power source for triggering said X-ray source in phase with the synchronous motor.

20. An apparatus according to claim 18 wherein the motor is a permanent magnet synchronous motor.

21. An apparatus according to claim 14 or any one of claims 15 to 20 as dependent on claim 14, wherein the edge mask is made from cardboard.

22. An apparatus for inspecting objects, substantially as herein described with reference to the accompanying drawings.

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1428305 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

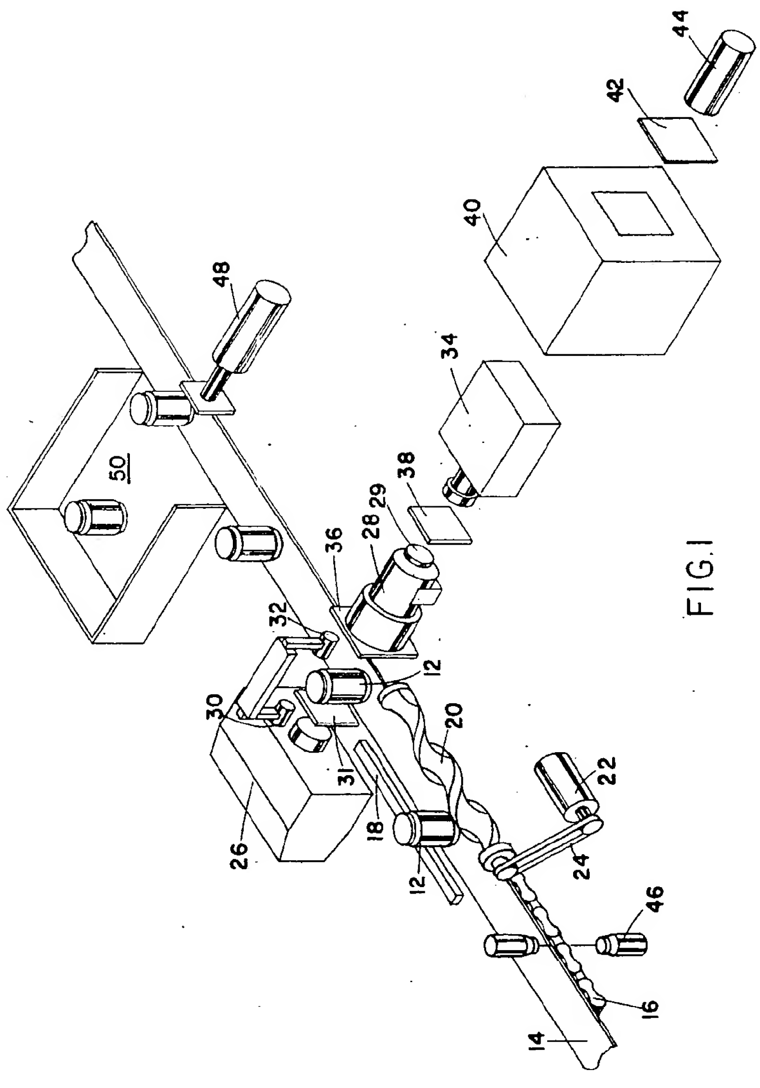

FIG.1

1428305 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 2

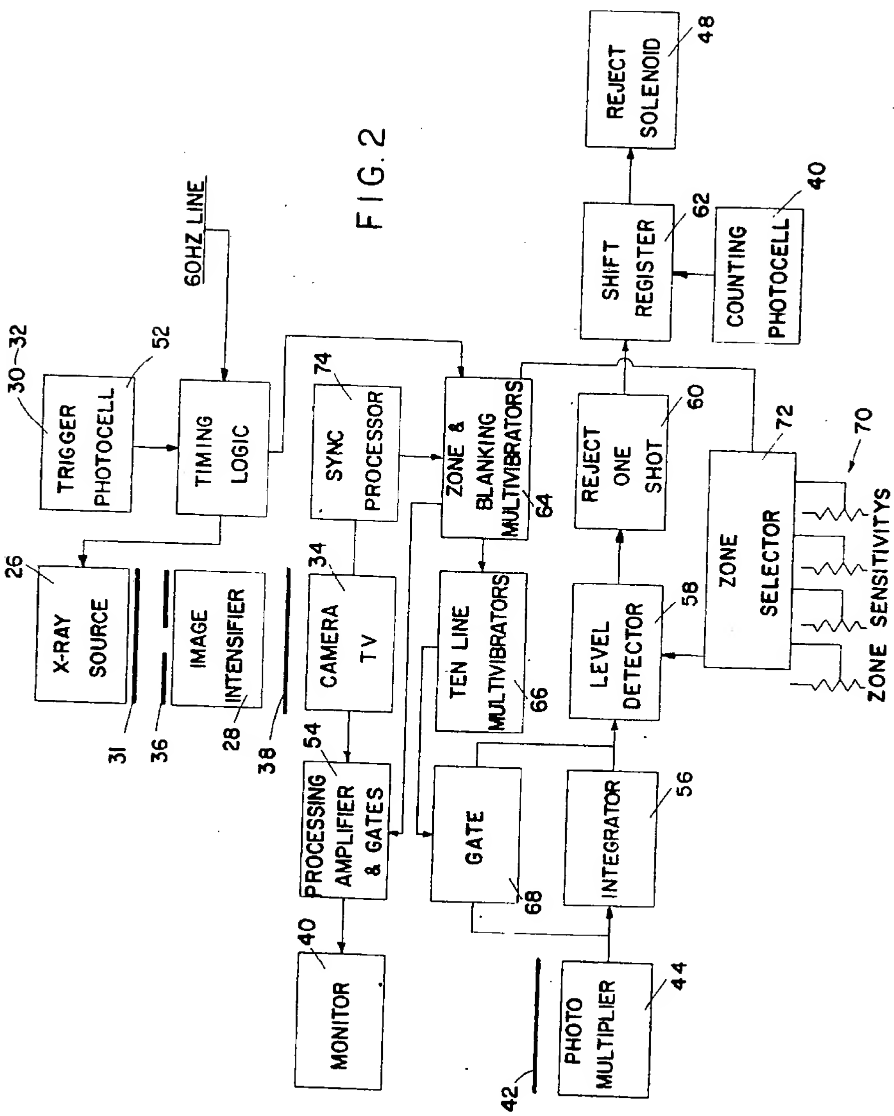

FIG. 2